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DESIGN, FABRICATION AND TESTING OF A SATELLITE ELECTRON BEAM SYSTEM

William B. Huber

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765 Concord Avenue
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1.0 INTRODUCTION AND OVERVIEW

This report covers the work performed under Contract F19628-75-C-0114 for the Air Force Geophysics Laboratory, Hanscom Air Force Base, MA. It covers the time period from January 1975 to December 1979.

1.1 Original Contract Specifications

The original contract specifications called for the development, fabrication, and test of an electron beam system suitable for use in a satellite vehicle, using a Machlett Laboratories type EE-65-1 electron gun furnished by the government. A further contract requirement, was the design and fabrication of support equipment for testing and monitoring the electron beam system during acceptance tests, and during installation and vehicle integration phases of the satellite vehicle.

1.2 Scientific Objectives of The Satellite Electron Beam System (SEBS)

The scientific objectives of the SEBS was the ejection of electrons from what later became the SCATHA (Spacecraft Charging At High Altitudes) satellite. Three areas of investigation using negative charge ejection were planned: (a) Determination of the current and energy magnitudes of beam electrons to restore the spacecraft frame to ambient plasma potential after it becomes highly negatively charged due to the flux of energetic electrons from the ambient plasma: (b) Determination of the magnitude of charge ejection current to prevent charging of the spacecraft frame during sub-storm periods: and (c) To swing the spacecraft frame to a positive potential relative to the ambient plasma at predetermined times for predetermined periods.

1.3 Investigation Of The Machlett EE65-1 Gun At Other Than Design Levels

The EE65-1 electron gun which was originally designed for space applications and was previously used in rocket probe experiments was not specified at the low beam energy-high beam current levels. Two government-furnished tubes were tested in these low power modes. This effort led to final design specifications for the satellite electron beam system. A design review was held with representatives of AFGL and the operating specifications, electrical design, and mechanical design was approved with the exception of a break-seal gun cap opening system. It was felt that the electrical break-seal design used in rocket probe experiments was not suitable for satellite applications.

1.4 Development Of One Flight Model Of SEBS

One flight system was fabricated and tested. In conjunction with AFGL personnel and a separate government contract with Machlett Laboratories, the EE65-1 electron gun was modified mechanically and a new gun cap opening mechanism was developed using an electro-explosive device.

During this time interval the contract for the SCATHA satellite, P78-2, was awarded to Martin-Marietta Corporation. Vehicle-to-experiment interface control documents were developed and the satellite command, telemetry, power, and experiment layout were defined. Spacecraft environmental levels were calculated and experiment qualification and acceptance test levels were set.

1.5 Contract Modifications

The work effort with Martin-Marietta on Interface Control Documents led to contract changes, most important of which were the following: (a) Modification of SEBS to conform to the P78-2 requirements, (b) Fabrication of a second SEBS so that the flight unit would only be subjected to instrument acceptance test levels and not the more stringent flight qualification levels which would probably reduce the instrument flight lifetime, and (c) The addition of the responsibility of engineering support for the qualification and acceptance testing and integration testing of the Satellite Positive Ion Beam System (SPIBS). The SPIBS was designed and built for AFGL by Hughes Research Laboratory of Malibu, California, under Contract No. F19628-75-C-0066.

Other hardware requirements included the design and fabrication of laboratory test instruments and fixtures for the determination of beam dimensions in a vacuum chamber, and the design and fabrication of mechanical check templates and volume and electrical simulators for use by Martin-Marietta before integration of the flight unit into the spacecraft.

1.6 Description of SPIBS

The SPIBS instrument was a two centimeter diameter ion source using Xenon gas as the expellant, having a hollow cathode with an oxide-impregnated insert. It also had a naked yttrium-doped tantalum filament external to the ion source, but close to the ion beam exit such that when the ion beam was operating, the electrons from the hot filament could be coupled to the beam producing a neutralized beam of ions and electrons. Provision was also made to bias the neutralizer filament both positive and negative with respect to spacecraft frame.

1.7 Scientific Objectives Of The SPIBS

The scientific objective of the SPIBS was the ejection of charged particles, positive ions, or electrons, or neutral beams containing both positive ions and electrons. It was planned to use the SPIBS in operations designed to move the space vehicle frame to ambient plasma potential positive and negative and to keep the vehicle frame at, or discharge it to, essentially zero potential.

1.8 Qualification And Acceptance Testing Of Both Instruments

The engineering models of both the SEBS (designated Experiment No. SC4-1 on the SCATHA satellite) and SPIBS (designated Experiment No. SC4-2) were environmentally tested to qualification levels. These tests included vibration, shock, thermal-vacuum, and electromagnetic compatibility tests. Test levels were established by calculated stresses due to location on the spacecraft. Success criteria were determined by system performance requirements.

System testing of SEBS was considerably more simple than that of SPIBS. The break-seal opening mechanism on the engineering model of SEBS was fully tested using dummy guns. Special gun opening tests using real guns were employed in vacuum tests to determine that there was no cathode poisoning due to the firing of the electro-explosive device for the cap removal. An open gun was also used to measure beam dimensions in a vacuum system. All other testing of the SEBS was accomplished using a closed gun with beam return to the sealed end cap. Since the gun was basically a vacuum tube it carried its own vacuum environment with it, which environment did not deteriorate with use, whether the tests were conducted with the instrument in vacuum or at atmospheric pressure.

Complete systems tests of SPIBS required the flow of expellant gas. The ion source was enclosed in a vacuum-tight cover for protection from the environment prior to launch. The cover had a squib-actuated door release mechanism designed by AFGL personnel. The door was deployed on orbit.

The door was designed with a special pump-out port which could be opened or closed while connected to a semi-portable turbo-vacuum pump. With this test set-up the SPIBS system could be completely checked for proper operation even to the level of producing an ion beam within the cover. This setup was employed during EMI testing, post vibration and shock tests, bench tests at Martin-Marietta, vehicle EMI tests, vehicle integration tests at the integrators plant and at the launch integration area.

The qualification test program uncovered some problem areas in both instruments. The SEBS had two electrical failures due to mechanical weaknesses in the instrument assembly. These were revealed during vibration and shock tests. Slight design changes eliminated the problems as proved by successful re-test.

In parallel with the SPIBS qualification program a rocket model of SPIBS was flown on an Astrobee F rocket in January of 1978. The integration of this system was carried out by TRI-CON ASSOCIATES under contract with AFGL. (Contract No. F19628-76-C-0230). In the course of integration tests of this payload it was found that although every telemetry output channel was protected by a zener diode with a one thousand ohm current-limiting resistor, sufficient energy was coupled to the output lines during ion chamber arcs to destroy an analog multiplexer chip in the flight PCM system. It was found that 0.1 microfarad capacitors from each output line to ground on a separate assembly external to the rocket model SPIBS was sufficient to restrict these occasional transients to less than 30 volts. This assembly was added to the rocket payload with no subsequent failures observed in the integration test program.

This experience led to an investigation of the satellite model SPIBS and its application in the SCATHA satellite. The use of a Biomation Waveform Recorder revealed the presence of discharge related transients on the command lines as well as the telemetry lines. These transients were in the order of 100 to 150 volts and in the order of tens of nanoseconds wide. The frequency of occurrence was less than two per hour.

A separate interface box with cables was designed and built through which all telemetry and command lines from the space vehicle were routed. Redundant fast zener diodes and capacitors were used to protect each line. The transients were limited to less than seven volts on the telemetry lines and less than forty-five volts on the command lines.

Thermal-vacuum tests on the SPIBS pointed up the desirability of having a monitor of the state of the expellant valve. The pressure transducer which monitored tank pressure was mov from the inlet side of the latching valve to the outlet side, actually on the inlet to the pressure regulator. This still provided a measure of tank pressure (and expellant reserve) when the valve was opened and the characteristic drop in pressure for up to three hours after the valve was closed. This provided the additional feature of a monitor of the valve closure sharing the same telemetry channel for the measurement of tank pressure.

Pyrotechnic shock measurements were made at the structural interfaces of both instruments to insure that the shock levels of cap openings were less than those prescribed by the Interface Control Document.

The SPIBS auxilliary unit with the transient suppressors for the telemetry and command lines was also tested to levels calculated from its location on the space vehicle.

1.9 Acceptance Testing of Flight Models Of Both Instruments

The acceptance test program was essentially the same as the qualification program except that the stress levels were lower. The electromagnetic compatibility tests were not repeated since they were a design check and not a stress test. The only failure occurring in this program was a discharge transformer high voltage breakdown from secondary to grounded electrostatic shield winding in SPIBS. The transformer was replaced with a flight level tested spare and the flight instrument was re-tested without further trouble. An attempt at analysis of the failed component was unsuccessful in determing the exact cause of failure.

1.10 Integration Into The SCATHA Satellite

The particle beam instruments were delivered to the integrators plant in the Spring of 1978. The units were bench tested per an established electrical test procedure. The SPIBS was fully tested using the semi-portable vacuum system connected to its ion chamber cover. The instruments were accepted and then were given a component level magnetic survey. SEBS passed the requirement of a remanent magnetic field at a distance of one meter no more than 4×10^{-4} gauss.

The SPIBS system utilized a permanent magnet system in its ion chamber and provision was made to add compensating magnets on the cover of the power processor electronics to reduce the far field effects of the permanent magnets. The magnetic survey facility at Martin-Marietta provided an excellent means for determining the direction and magnitude of the field of the compensating magnets required to reduce the remanent magnetic field to less than one milligauss at a distance of one meter from the center of the instrument.

After the magnetic survey the space vehicle was built up using the electrical and volume simulators. Space vehicle subsystems were integrated and checked out using the payload instrument simulators. Experimenters supplied check templates with gage pins which were used to checkout the payload flight unit mounting interfaces.

When the mechanical, power, command, and telemetry interfaces were checked out, the payload flight units were installed and given a complete system performance check. An integrator contractor supplied van contained all the necessary data processing equipment, decommutators, printers, and tape recorders for all space vehicle and instrument telemetry data outputs.

The SPIBS system was checked out with the semi-portable vacuum system hooked up to the pump-out port on the ion chamber cover while the instrument was in place on the vehicle.

In order to maintain a single point ground return from the space vehicle to external test equipment while in the integrated systems test configuration, the SPIBS vacuum system had to be insulated from the SPIBS cover and box. This was achieved through the use of a teflon flange in the vacuum piping to the SPIBS cap port.

In the early functional testing of the payloads on the space vehicle, it was noted that at certain levels of input power voltage, the SEBS presented out-of-tolerance line voltage noise on the power line. An investigation showed that one of the SEBS input switching power regulator was squegging at very limited input voltage ranges. A change of value of two frequency response compensation capacitors eliminated the problem. The SEBS flight unit was removed from the vehicle and the changes were made at TRI-CON in Cambridge, Massachusetts.

The SEBS flight unit was returned to Martin-Marietta and the in-coming inspection and electrical bench checks were repeated. The unit was re-installed on the vehicle and the line noise problem never again appeared.

1.11 Space Vehicle Environmental Tests

After all vehicle subsystems and experiment payloads were installed and individually checked out, experiment alignment checks were made. Then a full integrated systems check was performed with all subsystems and experiments.

A spacecraft EMC test was performed. Significant operating conditions for the particle beam systems were: (1) The portable vacuum system was used with SPIBS so that a full power test was accomplished with a cap-contained beam, and (2) The SEBS was operated in the high power pulsed mode of 3 KV energy and 13 milliampere current level and 6.25% duty cycle pulses. These conditions represented maximum power and worst case operating condition in terms of power line induced noise. The particle beam experiments were operated for two hours in these operating modes during conducted interference tests. A biomation waveform recorder was used to monitor the experiment power buss with triggers set for ± 2.5V and no signals were found out of specification. Other experimenters after examination of their test data dumps offered no complaints of interference or degradation of performance of their experiments. Since the particle beam experiments were the highest power experiments and represented the greatest possible source of interference, the vehicle EMC test success was considered a significant milestone in the SCATHA development.

The satellite was subjected to shock and acoustic tests and then placed in the large thermal-vacuum facility at the Martin-Marietta plant. There were no problems encountered in the operation of SEBS using a closed gun. SPIBS was operated with the ionization chamber cap latched closed but with the pump port in the cap opened. This allowed the SPIBS to be operated with a beam and at full power. The system operated reasonably well but the internal temperatures were consistently lower than predicted. After operation the pressure monitor remained high for long periods of time indicating either the latching valve was stuck in the open position or xenon gas liquified in the volume between the valve and the pressure regulator due to the high pressure and unexpectedly low temperatures. The latter proved to be the cause since after the temperature of SPIBS was raised the pressure monitor consistently reduced to zero within a few hours. Some modifications to the thermal control coatings in the vicinity of SPIBS were made to limit the low excursion of temperature during eclipse periods. The Interface Control Document was also amended to allow operation of SPIBS down to -20°C instead of 0°C. After thermal-vacuum tests the final acceptance Integrated Systems Test was performed.

1.12 Tests At GSFC And ETR

The satellite was then shipped to Goddard Space Flight Center where moment of inertia and center of gravity verifications were performed. A magnetic survey was also performed. The SPIBS experiment was removed during these tests for re-calibration, inspection, and replenishment of the expellant gas. It was decided to replace the ionization chamber head of the SPIBS because of evidence of contamination and wear of the neutralizer filaments. The expellant gas supply was also replaced. The system was tested in a laboratory vacuum system and the unit was hand carried to Goddard Space Flight Center for magnetic survey, both at the component level and mounted in the satellite. The compensating magnet assembly had to be changed due to a reversal of magnet polarity in the new ionization chamber head.

The satellite was shipped to Eastern Test Range and the SPIBS was hand carried. Bench tests were performed on SPIBS using the portable vacuum system. Satisfactory all-modes tests were performed and the unit was re-mounted on the satellite. Again the vacuum system was used for all-modes tests operated with the satellite power, command, and telemetry system.

System compatibility tests using communication links with Satellite Control Facility were made after special training sessions were held to familiarize all personnel with the operation of the satellite.

1.13 Launch And On-Orbit Tests

The satellite was launched on 29 January 1979. The SC4 experiment payloads were not powered during ascent and during the transition orbit. After insertion into final near geo-synchronous orbit all experiments were checked out, one at a time. The caps of both the electron and ion guns were removed successfully. A series of tests were performed with each gun and each of the other experiments to demonstrate experiment compatibility with the particle beams in the open space environment.

In general these tests were successful. The details of operation of the SCATHA satellite experiments are not a subject of this report.

The particle beam systems have been operated for more than a year. Performance has met the design goals. The electron gun was operated over the wide dynamic ranges of energy (.05 to 3.0 kilovolts) and current level (microamperes to milliamperes). The electron gun was operated in the continuous and pulsed mode. It was used to achieve all of the original scientific objectives.

The positive ion experiment also achieved all of its original scientific objectives.

In over a year of operations with the particle beam systems the following anomalies occurred:

SC4-1 Satellite Electron Beam System

1.) During a test operation on the eighty-ninth day in orbit after the SEBS was operated at high energy and current level, the pulsed mode of operation failed. Later tests with a redundant timing distribution unit on the Satellite Timing and Command Distribution Unit indicated that the malfunction persisted. This localized the problem to the timing wiring to SEBS and the input buffer gate, U1, on Figure 4. The failure effectively kept the output on pin 2 of U1 down at zero volts and therefore the input to gate U2, pin 5, positive. It should be noted that during the above mentioned operation the vehicle was driven to high positive potentials with respect to plasma as measured by other payload instruments. Spherical Probes SC2-1 and SC2-2 mounted on three meter booms were permanently damaged during this pass.

2.) Over the operating life of SEBS in space, the oxide-coated cathode had poisoned such that in March of 1980, the maximum obtainable beam current was 400 microamperes. The cause of the contamination is not known. Likely candidates for responsibility are long term out-gassing of the whole vehicle and the hydrazine rocket control system used for orbit trim and attitude control.

SC4-2 Satellite Positive Ion Beam System

1.) Both neutralizer heaters failed open, one in the Spring of 1979 and the other in the Spring of 1980.

Both failures occurred during operations which caused the heaters to be rapidly sequenced on and off. The emission control loop adjusts heater power or heater temperature to maintain a commanded emission current level as measured by an electrometer in the neutralizer circuit. Because of the thermal lag in the heater, the response of the control loop is seconds. When the heater is turned on the loop forces the heater power to maximum until the emission current reaches normal value. This stress, especially if applied many times in immediate succession apparently weakens the heater and eventually causes it to open.

2.0 DETAILS OF THE SATELLITE ELECTRON BEAM SYSTEM DESIGN

2.1 Machlett EE65 Electron Gun Description

The Machlett EE65 electron gun has a heater-cathode and control grid assembly which is basically that of a power triode. In addition it has a focusing anode, accelerating anode and an end cap or collector. The collector is used as a beam return circuit before the gun is opened. In the original design of the EE65 there was a band of moly-manganese fired to the outside of a ceramic tube between the end cap and the accelerating anode ring. This band was two mils thick and about one-eighth inch wide. The cold resistance was about one-quarter ohm.

When sixteen volts from a suitable supply was applied to the band, the high current of about sixty amperes heat-stressed the ceramic cylinder causing it to crack evenly around the tube. The end cap was fixed to a spring loaded arm which carried the cap to the side of the gun assembly after the ceramic tube was cracked. In the process of opening the gun the moly-manganese band was open-circuited, shutting off the power drain from the supply. The gun opening required two to three seconds. This method of opening the EE65 electron gun was successfully tested many times and successfully used in sounding rocket instrumentation.

In these applications of the EE65, the minimum cell size for flight supplies to provide the sixty amperes was the Yardney HR-15 cell, rated at fifteen ampere-hours.

Since both the voltage and peak power levels were not readily attainable on a satellite, Machlett Laboratories was asked to change the design of the ceramic tube between the accelerating anode ring and the end cap. The moly-manganese band was reduced to one mil thickness by approximately fifty thousandths wide. This increased the cold resistance to approximately one ohm.

On the inside surface of the ceramic cylinder, directly under the moly-manganese band, a groove was machined to reduce the cylinder wall thickness. Successful tube breakings were made using twenty-eight volts at approximately twenty-five amperes for approximately three seconds.

In parallel, a squib-actuated wedge mechanism was designed by W. Lynch of AFGL to separate the end cap from the ceramic cylinder at the brazed joint between the cylinder and the cap. This method of opening the gun was tested successfully many times on dummy guns at atmospheric pressure. A series of tests on guns was carried out to determine the effect of out-gassing, if any, of the expended squib on cathode poisoning. Using the same design as that eventually flown on SCATHA there were no deleterious effects detected. It was therefore decided to use redundant AFGL wedge mechanisms for the cap opening device. This produced a greatly reduced power requirement for the satellite compared to the electrically operated heat-stressed band.

2.2 Results Of Gun Tests At Low Energies

The original design goals for the SEBS were: (1) As much beam current as possible within the restriction of fifty watts maximum with the instrument, and (2) As much dynamic range both in beam current and energy as possible.

The first goal depends upon the electron tube geometry and operating conditions. The EE65 electron gun is capable of forming a beam with a current of seventy-five milliamperes at ten kilovolts of accelerating potential. At low energies the beam is poorly defined and a significant amount of power is expended in the anode ring.

End cap and anode ring characteristic curves were plotted for two EE65 electron guns (S/N 384 & 394) in the 500 volt to 3000 volt region. Assuming that twenty watts of beam power would require fifty watts of input power to the instrument, maximum beam current (cap current) at less than twenty watts beam power would occur at an energy level of 1500 volts. At this voltage the cap current was 13 milliamperes. The anode ring current was 4 milliamperes. The control grid drew about 5 ma.

Variation in focus voltage up to ten percent of the accelerating voltage had little effect on the cap current but a large effect on anode ring current in the accelerating voltage range of 500 volts to 3 KV. However, the anode ring current was minimum at a focus anode voltage approximately 1% to 5% of the accelerating voltage and increased with focus anode voltage.

All of the tube characteristic curves were taken at a filament power level of 7.5 volts at 0.9 amperes. Spot checks of the curves at the nominal heater power of 6.3 volts at 0.75 amperes produced similar data.

Further tests were performed down to accelerating voltages of fifty volts to try to determine if a significant beam current could be generated at low energy levels. It was found that a beam current of one milliampere was possible down to energies of one hundred and fifty volts, and a beam current of one hundred microamperes down to energies of fifty volts.

At the maximum beam current for fifty watts of input power, the power breakdown for a flight instrument is as follows:

Beam Power	19.5 watts
Heater Power	7.5 "
Anode Ring Power	6.0 "
Instrument Control Power	5.0 "
	38.0 watts
Assumed 75% efficiency	50.6 watts input power

Arbitrarily assigning three kilovolts as an upper boundary on accelerating potential, the maximum beam current at this potential in a non-pulsed mode of operation was six milliamperes.

2.3 Definition Of System Design With Power Constraints Using Test Results

The design goals re-defined with the constraints of maximum beam current at no more than fifty watts input, maximum beam energy of three kilovolts, and a maximum dynamic range were: 6 levels of electron energy: 3 KV, 1.5 KV, 500V, 300V, 150V, 50V: 6 levels of beam current: 13 ma, 6 ma, 1 ma, .1 ma, .01 ma, .001 ma. The above two parameters were commandable in any combination. However, the combination of three kilovolts at thirteen milliamperes exceeded the maximum input power level and was automatically locked out of the command circuits. The combinations of low energy and high currents were not possible due to the electron tube geometry.

In addition to the two six-level functions described above, one of three possible focus voltages were setable by ground command. Best focus values as defined by least anode ring current for maximum beam current, were 0%, 5%, and 10% of the accelerating potential.

It was desirable to operate the electron beam system in a pulsed mode producing another factor of ten or so in average beam current dynamic range as well as provide a dynamic stimulus for the analysis of spacecraft charging phenomena at high altitudes. It was decided to use a duty cycle of one-sixteenth (6.25%).

The SCATHA space vehicle PCM system had a mainframe length of 128 words and a frame rate of 8 per second. Using a timing gate equivalent to four successive words, twice per frame (duty cycle of one-sixteenth) the beam-on time was 3.9 milliseconds at a pulse repetition rate of 16 per second.

2.4 Power Supply Design

The schematic diagrams for the electron beam system power supply is shown on Figures 1 and 2.

On Figure 1, the input power lines contain a filter composed of C101, L101, and C102 to reduce conducted emissions from the power supply switching regulators and power inverters. The output of the filter powers two switching regulators, U101 and U102. U101 with its pass transistor switch circuit, Q101 and Q102, storage inductance, L102, commutating diode, CR102, and output filter, C103 and C104, produces a fixed twenty volt regulated output which supplies power for the master inverter oscillator Q201, Q202, and T202 on Figure 2 and slave power inverter Q105, Q106, and T102.

U102 with its pass transistor switch circuit, Q103 and Q104, energy storage inductance, L103, commutating diode, CR103 and output filter, C110 and C111, produces a four level regulated output voltage, programmed by command relays, K101 and K102.

The master oscillator is a low power, ferrite core transformer type designed to free-run at twenty KHz. It is synchronized by the presence of a twenty-five KHz signal from the space vehicle system on the primary of T201.

The transformer isolates power ground from the signal ground return of the synchronizing signal. (The synchronization requirement was removed from the SCATHA requirements and diodes CR201 and CR203 were removed from the final flight configuration of the SEBS).

The secondary winding, 7-9 of the master oscillator transformer provides a boot-strapped three and one-half volt supply on top of the input twenty-eight volts so that both switching regulator pass transistors may be bottomed at low input line voltage and therefore maintain high switching efficiency.

Windings 10-12 and 13-15 of the master oscillator transformer provide base switching signals for both power inverters. Either signals for both switching regulators are taken from the collectors of the master oscillator switching transistors. Note that these signals are presented to the switching regulators on alternate half cycles of the oscillator. Therefore, the switching regulators and the power inverters are all synchronized to the master oscillator.

The power inverters are non-saturating ferrite core type. The slave power inverter consisting of Q105, Q106 and T102, provide the fixed power supply voltages for the electron beam system. Winding 4-6 of T102 provides +5 volts referred to ground for the TTL logic in the input timing gate circuits. Winding 7-9 provides $\pm$ 15 volts referenced to ground for the telemetry buffer amplifiers and other analog circuits referenced to ground. These voltages are post-regulated by U103 and U104.

Winding 13-15 provide square-wave heater power for the electron gun. This winding floats at the negative high voltage of the beam energy power supply.

Winding 10-12 provide the square-wave power to rectifiers CR220 and filters C214 and 215 producing $\pm$ 35 volts referred to the negative high voltage of the beam energy power supply.

Transformer assembly T101 is a five toroid assembly. Sections A and B with their respective diode bridge assemblies, CR209 and CR210, develop 750 volts each with 20 volts on the center taps of their primaries. Sections C, D and E and their respective bridge rectifiers CR211, CR212 and CR213, develop 500 volts each with 20 volts on the center taps of their primaries.

The five secondary voltage outputs are wired in series to form the beam energy high voltage supply. The primaries of Section A and B of T101 are driven by inverter transistors Q105 and Q106 through command relay K103 in the 3 Kv command mode only. The primaries of Sections C and D are driven by transistors Q107 and Q108 through command relay, K104, in the 3 Kv and 1.5 Kv command modes only. The primary of Section E is always driven by transistors Q107 and Q108. In the 3 Kv, 1.5 Kv and 500 V modes the primary center taps of the transformer are at 20 volts. In the 300 V, 150 V and 50 V modes the center tap of Section E is reduced to approximately 12, 6 and 2 volts respectively by changing the feedback divider for switching regulator U102 with relays K101 and K102.

Those secondary supplies that are in the off state in other than the 3 Kv mode of operation look like short circuits due to the forward biasing of the rectifier diodes.

U105 is the diode matrix which determines the states of relays K101 through K104. Table I shows the relay states, sections of T101 energized, and output voltage of programmed switching regulator, U102, as a function of input command signal. Note that the sections of T101 which are powered are a function of K103 and K104 and the programmed regulator voltage is a function of K101 and K102.

Five-volt command verification flags are generated which monitor the states of the beam energy relays. F10 and F11 are generated from five volt windings on T101, Sections C and E, which are referred to signal ground. When the transformer sections are energized, the 20 KHz square-wave signal is half-wave rectified and filtered to produce five volts or a "one" to the PCM system. When the transformer section is not energized, it represents a very low impedance to ground and the negative fifteen volt return of the flag circuit load resistor keeps the rectifier on and produces a negative 0.6 volts or zero to the PCM system. This method of flag generation is required since both available poles of the relays being monitored, K103 and K104, are used.

Flags F12 and F13 monitor the status of K101 and K102. These flags are generated from the logic power supply voltage of +5 volts and are picked off the unused poles of the relays.

	RELAY STATES					
COMMAND	K101	K102	K103	K104	SECTIONS OF T101 ON	U102 REGULATOR OUTPUT
3 KV	Reset	Reset	Set	Set	A,B,C,D,E	20 Volts
1.5 KV	Reset	Reset	Reset	Set	A,B,C	20 Volts
.5 KV	Reset	Reset	Reset	Reset	A	20 Volts
.3 KV	Set	Reset	Reset	Reset	A	12 Volts
.15 KV	Reset	Set	Reset	Reset	A	6 Volts
.05 KV	Set	Set	Reset	Reset	A	2 Volts

TABLE 1

BEAM ENERGY COMMAND RELAY STATES

The states of the four beam energy level flags as a function of input commands is shown on Table 2, F10 through F13.

On sheet two of the power supply schematic, a high impedance divider R212 through R229 is shown across the beam energy supply. This provides taps at the high end of the divider for voltage levels for the focus anode of the electron gun. A tap at the low end is used to develop an analog monitor voltage of the high voltage supply. The bottom end of the divider is established at a virtual ground by means of the beam current control amplifier, to be described later. The divider return current is not measured by this amplifier and therefore does not introduce an error in the control. U201 is a very high impedance unity gain amplifier to buffer the divider monitor. U201 is an inverting amplifier with gain switch as a function of beam energy command. When K101 or K102 or both are set (300 V, 150 V or 50 V command), Q203 is turned on and relay, K203 is closed, shorting out R234, increasing the gain by a factor of approximately ten. The focus relays change the resistor divider at the top of the monitor string of resistors, changing the overall gain of the high voltage monitor slightly.

Table 3 shows the variation of the high voltage monitor circuit with beam energy and focus commands.

The gun focus anode voltages are approximately 0%, 5% and 10% of the beam energy supply, tapped down from the negative high voltage. The focus switches are small reed relays, K201 and K202 capable of 3 Kv isloation between

TLM FLAG OUTPUTS VS COMMAND STATUS

		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
<u>BEAM CURRENT LEVEL</u>	13 ma	0	1	1	1	1	-	-	-	-	-	-	-	-	-
	6	1	0	1	1	1	-	-	-	-	-	-	-	-	-
	1	1	1	0	1	1	-	-	-	-	-		-	-	-
	.1	1	1	1	0	1	-	-	-	-	-	-	-	-	-
	.01	1	1	1	1	0	-	-	-	-	-	-	-	-	-
	.001	1	1	1	1	1	-	-	-	-	-	-	-	-	-
BEAM ON		-	-	-	-	-	1	-	-	-	-	-	-	-	-
BEAM OFF		-	-	-	-	-	0	-	-	-	-	-	-	-	-
BEAM DUTY CYCLE	100%	-	-	-	-	-	-	1	-	-	-	-	-	-	-
	6.25%	-	-	-	-	-	-	0	-	-	-	-	-	-	-
FOCUS	HI	-	-	-	-	-	-	-	0	0	-	-	-	-	-
	MED	-	-	-	-	-	-	-	1	0	-	-	-	-	-
	LO	-	-	-	-	-	-	-	0	1	-	-	-	-	-
<u>BEAM ENERGY LEVEL</u>															
	3KV	-	-	-	-	-	-	-	-	-	1	1	0	0	-
	1.5	-	-	-	-	-	-	-	-	-	1	0	0	0	-
	.5	-	-	-	-	-	-	-	-	-	0	0	0	0	-
	.3	-	-	-	-	-	-	-	-	-	0	0	1	0	-
	.15	-	-	-	-	-	-	-	-	-	0	0	0	1	-
	.05	-	-	-	-	-	-	-	-	-	0	0	1	1	-
GUN CAP IN PLACE		-	-	-	-	-	-	-	-	-	-	-	-	-	1
GUN CAP DEPLOYED		-	-	-	-	-	-	-	-	-	-	-	-	-	0

TABLE 2

	HIGH BEAM ENERGY (3 KV, 1.5 KV, 015 KV)	LOW BEAM ENERGY (300 V, 150 V, 50 V)
Low Focus	- .00146	- .0149
Med Focus	- .00139	- .0143
HI Focus	- .00133	- .0136

HIGH VOLTAGE MONITOR CIRCUIT GAIN (VOLTS/VOLT) VERSUS BEAM ENERGY & FOCUS COMMANDS

NOTE: Above values do not take into account the effect of focus anode current at low accelerating voltages. Focus anode current tends to make the High Focus gain increase toward the Low Focus value.

TABLE 3

their contacts and their energizing coils. The coils are driven by contacts from command latching relays, K204 and K205. The diode matrix for the three focus commands are CR227 through CR232.

The electron gun accelerating anode is returned to the positive end of the high voltage supply which is at a virtual ground.

2.5 Beam Current Level Control

The floating electron gun cathode and grid driver circuit is shown on Figure 2. The other elements of the beam current control loop are shown on Figure 3.

U301 is a current to voltage amplifier with command-switched gain. Relays K303 through K307 are set, one at a time, by means of commands on the six current level command lines, through diode matrices U303 and U304. R325 is across the amplifier at all times. In the one microampere command mode, none of the five relays is set. In each of the higher current command modes one of the relays is set while all others are reset. This places an additional resistor in parallel with R325, changing the gain of the trans-resistance amplifier.

When the beam is on, the high voltage return current, either through the cap and logarithmic amplifier (to be explained later) or through the open gun and the environment to the space vehicle frame, must all pass through the feedback resistance of the amplifier, U301. The amplifier maintains its input at the reference voltage of pin 3 or zero volts. A positive current into the amplifier forces the output at pin 6 negative until the reference voltage of CR1, 6.4 volts, is reached. At this point Q301 starts to turn off, reducing the current to the photodiode of optoisolator, U204, on Figure 1.

This in turn reduces the current through the grounded base amplifier, Q204, and causes the output of amplifier U203 to go negative, shutting off the electron gun.

The control loop then is such that the output of trans-resistance amplifier U301 goes to -6.4 volts by adjusting the beam current of the EE65 electron gun. The electron gun current is therefore 6.4 volts divided by the resistance placed across U301.

The six commandable levels are: .001 ma, .01 ma, .1 ma, 1 ma, 6 ma, and 13 ma. Q302 is normally off when the command relay K301 is reset (100% Duty Cycle) and K302 is set (Beam On). However, if F11 is high (3 Kv command) and $\overline{E}$ is high (13 ma command) along with F7 (100% Duty Cycle), the condition is detected at pins 1, 2, and 13 on U302 turning on Q302 and shutting off Q301 and ultimately the electron beam. This is the one possible command mode that requires in excess of fifty watts of input power.

2.6 Performance Restrictions Caused By Dynamic Range Requirements

Because of the great dynamic range goals in both beam energy levels and beam current levels, certain compromises had to be made. The loop gain of the current control loop would change by 13,000 to one unless some means of compensating the gain change of the trans-resistance amplifier, U301, is made. Additional relays in order to reduce the loop gain as the beam current level became large, were considered and rejected because of weight and volume restrictions. A variable impedance electron gun cathode circuit was used. CR221 through CR226 and R239 through R244 form this variable impedance circuit. As more beam current (or cathode current) is drawn, the voltage across R239 increases, causing more of the diodes to conduct and placing lower impedances across R239. This effectively changes the gain of the electron gun by a factor of one to five thousand from beam currents of one microampere to thirteen milliamperes.

At a beam current of one microampere a few microvolts change between grid and cathode is sufficient to turn the gun off. Accordingly, the beam current at one microampere is one hundred percent modulated by noise, both random and power supply ripple. The lag time constant in the trans-resistance amplifier to stabilize the loop at this high gain is in the order of ten milliseconds, and therefore the beam cannot be pulsed at the four millisecond pulse width at this current level.

The power supply noise at the higher beam potential is higher. Over the complete range of beam potentials the one microampere beam level can be controlled only to within $\pm$ 30 percent.

Even at the ten microampere level the lag time constant in the trans-resistance amplifier required to stabilize the loop is in the order of one millisecond and the beam pulse is not a faithful reproduction of the square driving pulse. The 100 percent duty cycle control is good to within 5 percent.

At the lowest beam energy level of fifty volts, the gun geometry does not allow control of beam currents above 100 microamperes. At 150 and 300 volts the current cannot be controlled above one milliampere. At 500 volts the current cannot be controlled above six milliamperes.

At the low beam energies the cathode potential with respect to signal ground (beam potential) is a function of beam current because of the variable cathode impedance. The energy level at the fifty volt command mode can vary between 55 volts and 45 volts from one microampere to one hundred microamperes. The actual change in volts as a function of beam current remains approximately the same for each energy level but the percent variation from nominal energy level decreases as the high voltage level is increased.

2.7 Telemetry Interface Circuits

Figure 4 shows the space vehicle interface circuits for the instrument analog outputs and the timing gate input.

U407 is a buffer amplifier with a gain of -0.62 with its reference at ground. This samples the output of the trans-resistance amplifier which goes negative with beam return current. Since the trans-resistance amplifier gain changes with beam current commands, Table 4 lists the overall gain from beam return current to telemetry output.

U408, U401, and Q401 form a unpolar logarithmic amplifier which is used to measure the electron gun cap current prior to cap removal.

BEAM CURRENT COMMAND	TRANSRESISTANCE AMPLIFIER GAIN (FEEDBACK RESISTANCE)	X.62 (SIGNAL CONDITIONER) AMPLIFIER GAIN
.001 ma	6.8 meg.	4.22×10^{6} volts/amp
.01 "	647 K	4.01×10^{5} "
.1 "	63.4 K	3.92×10^{4} "
1.0 "	6.34 K	3.92×10^{3} "
6.0 "	1.05 K	6.51×10^{2} "
13.0 "	.499K	3.09×10^{2} "

TABLE 4

BEAM CURRENT MONITOR GAINS
AS A FUNCTION OF BEAM CURRENT COMMANDS

The transfer characteristic of the amplifier is $E_{TLM} = \log_{10} I_i + 6$, where I_i is in amperes. The cap current is passed through the logarithmic element to the amplifier power supply and on to the trans-resistance amplifier for linear measurement and beam current control.

U10 is a temperature monitor. The thermistor (T) is located on a printed circuit card retainer wall at the center of the assembly near the top plate. This is physically close to the electron gun socket where heater power of 4.75 watts is continuously expended when the instrument is on. The transfer characteristic of this circuit is:

$$T(^{\circ}C) = \frac{1}{A + B \ln R_t + C (\ln R_t)^3} - 273$$

where

$$R_t = \frac{4.88\, E_{TLM} + 4.63}{5.28 - E_{TLM}} \times 10_3 \text{ ohms}$$

and

$$A = 1.276 \times 10^{-3}$$
$$B = 2.380 \times 10^{-4}$$
$$C = 8.575 \times 10^{-8}$$

This produces temperature measurements from $-30^{\circ}C$ to $70^{\circ}C$ where +5V is equivalent to $-30^{\circ}C$, and 0V is equivalent to $+70^{\circ}C$.

Resistor dividers R22 - R23 and R24 - R25 provide monitors for the low voltage power supplies for diagnostic purposes in the case of flight data anomalies.

U1 is a Schmitt trigger input buffer for the beam pulse gating signal and the power supply synchronizing square-wave of 25 KHz.

S1 is a monitor microswitch located on the gun break seal mechanisim to monitor the deployment of the electron gun cap.

Table 2 is a list of discrete flags used to verify commands and gun cap deployment. Figure 5 is a graph of input power requirements versus the beam energy and current command settings.

2.8 Special Ground Test Equipment

Figure 6 is the front panel layout of the SEBS control console. The upper left-hand corner of the panel contains the instrument cable interface connectors and power line input. The top center of the panel contains the instrument power voltage and current analog meter monitor along with input voltage adjust.

The right hand side of the panel contains all of the command selection, execution, and monitor functions. Each switch position has a monitor pilot light driven by the bi-level flags from the SEBS instrument.

The command select switches provide a dual function in that they select, on a separate section of the switch, the individual flag outputs from the instrument and presents them to the appropriate test points for readout with external devices.

The commands and verification flags are broken up into groups according to function, beam current level (S5, S6 and TP2), beam energy level (S7, S8, and TP3), beam focus level (S9, S13, and TP5), beam duty cycle (S10, S12 and TP4) and beam on-off (S11, S14, and TP6).

Switches S5, S7, S9, S10, and S11 are command selection switches. The push button switches S6, S8, S12, S13, and S14 are the command execute switches.

The lower left hand corner of the panel layout contains the input power control and instrument power switches and monitor light along with a running time meter connected through the instrument power switch for logging test time.

The remaining front panel elements are for monitoring the analog telemetry outputs from the SEBS instrument. They consist of the 0-5 volt analog meter M3 and the associated selection switches below the meter. Test point RP1 allows the use of external monitoring devices to read the same output as that connected to the high impedance meter M3.

Figure 7 shows the front panel layout of the SPIBS Command Control Console. The SPIBS was designed without command verification flag outputs. The Hughes Research Laboratories ground test console provided only rotary selection switches and a command execute pushbutton. This required a command switch position versus command function table to operate and provided no memory as to commands entered after instrument initialization.

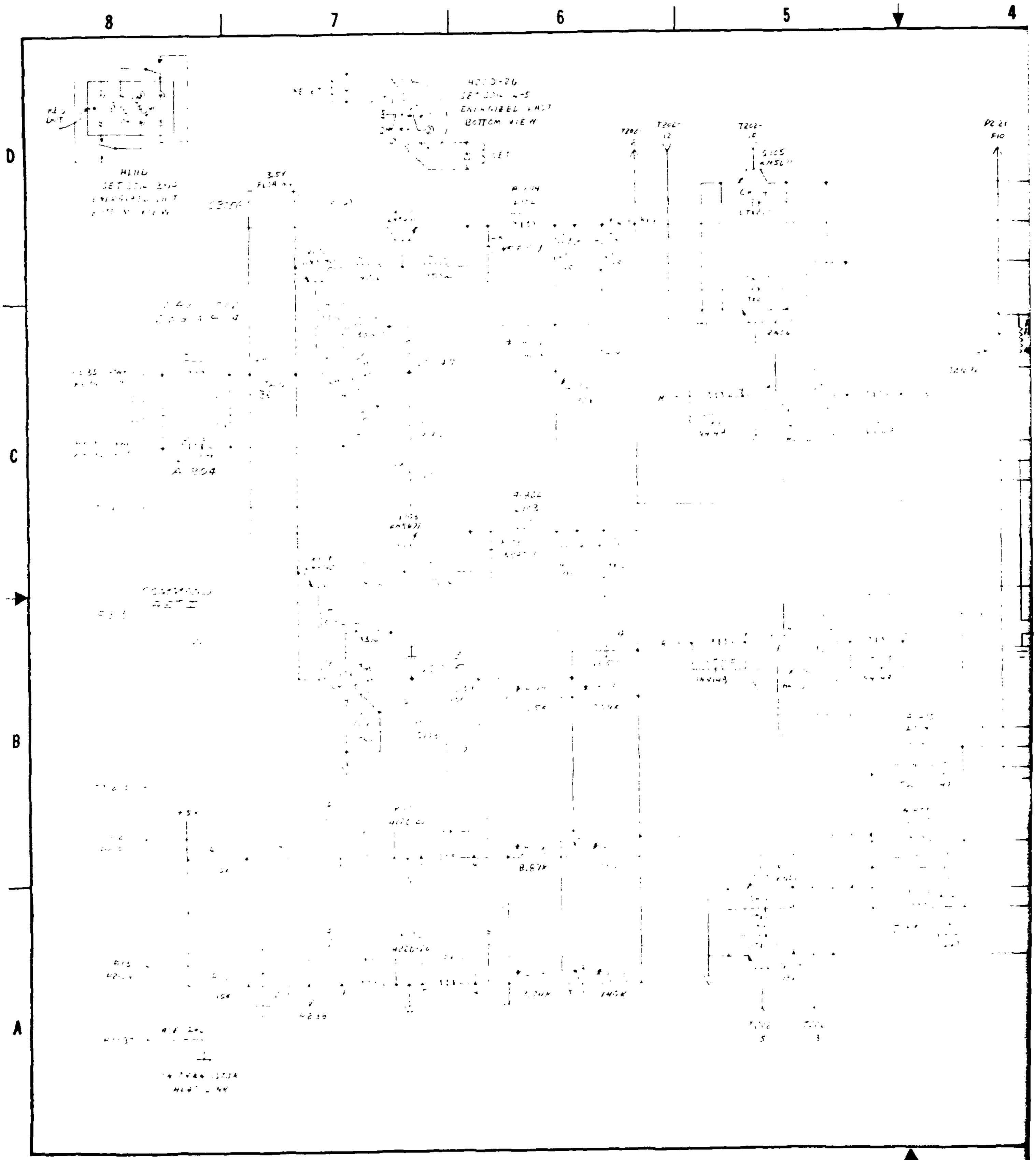
A new Command Control Console was designed and built to provide separation of command selection and execute switches according to command functions. The command switches on this new panel also have monitor lights to display the status of the instrument after initialization. Internal circuitry contains memory flip-flops which are set or reset according to command execution signals to the SPIBS instrument.

The upper left hand corner of the panel contains the AC power input for internal low voltage power supplies for the memory circuits and pilot light power, a 9 pin Canon D connector to bring 28 volt power from the Hughes Test Console to the Power Control Panel, and an AC power toggle switch to apply or remove power to the internal low voltage supplies. The 28 volt supply on the Hughes Test Console is variable from 24 volts to 32 volts for test purposes.

The upper right hand side of the panel contains a 50 pin Cannon D connector to carry the command signals to the SPIBS instrument, and a 50 pin Amphenol connector to carry digital signals to a digital printer for logging the command functions during tests.

As with the SEBS Command Control section of the Test Panel, the SPIBS commands are grouped according to control functions. In the lower left hand corner is the instrument power switch and the expellant valve command switches and monitor lights. The upper left hand side switch grouping concerns these commands dealing with the elements within the ionization chamber: cathode heater, discharge supply, keeper supply, screen/accel supply and screen/accel (beam voltage) magnitude.

The switches at the upper right hand section of the panel control discharge current and the magnitude of neutralizer emission when the neutralizer heater is on. The remaining switches concern the neutralizers: selection of redundant heaters, heater on-off, bias supply on-off and polarity, and neutralizer bias magnitude.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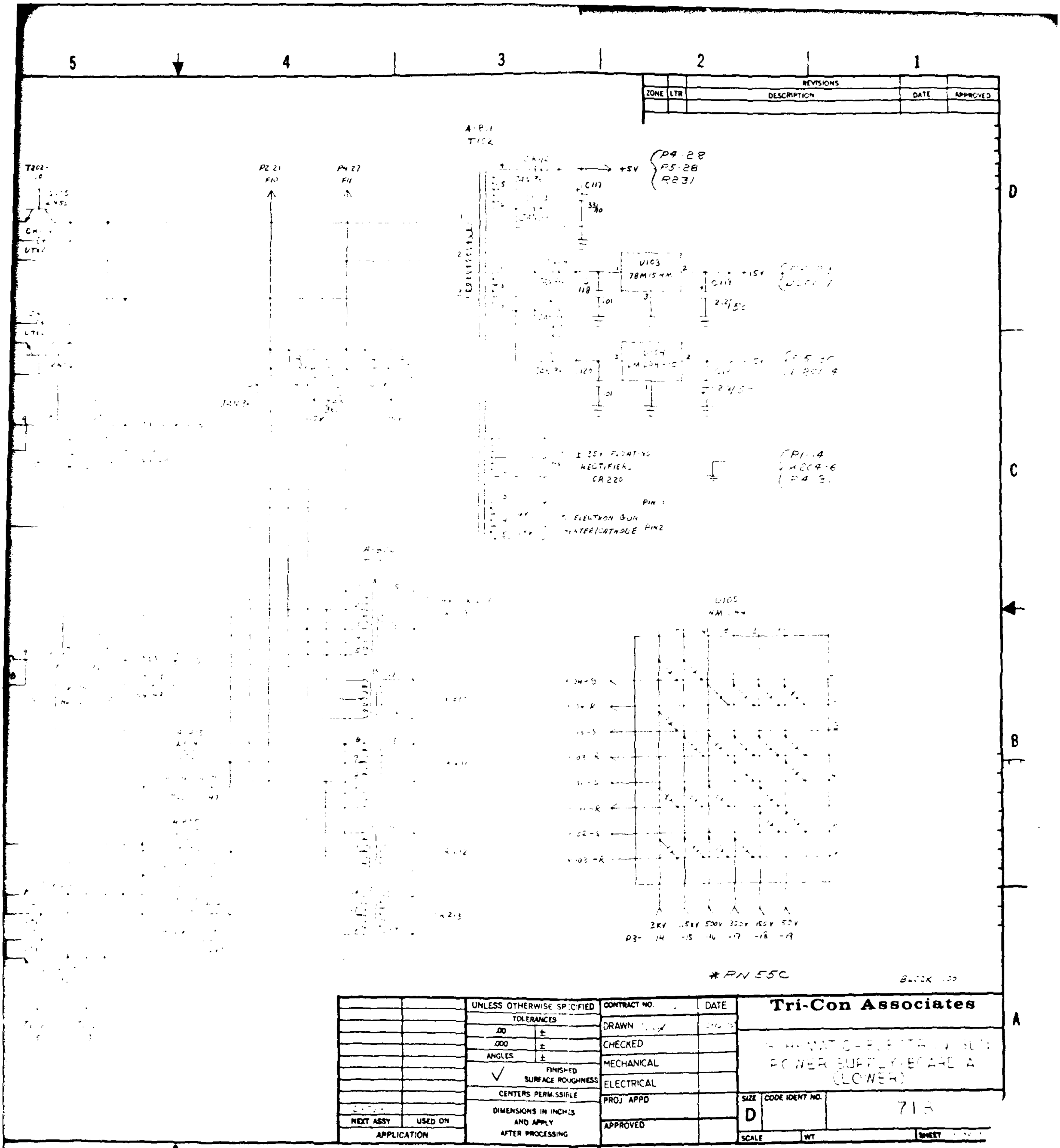
7
6
5
4
D
C
B
A
RELAY
SET COIL 3-14
ENERGIZED LAST
BOTTOM VIEW
4000-26
SET COIL 4-5
ENERGIZED LAST
BOTTOM VIEW
SET
3.5V
T202
T202
T202
S105
2N5671
P2-21
F10
A 804
A 802
2N5671
1N4148
8.87K
4220-26
10K
4239
100K
180K
PIN TRANSISTOR
HEAT LINK



REVISIONS
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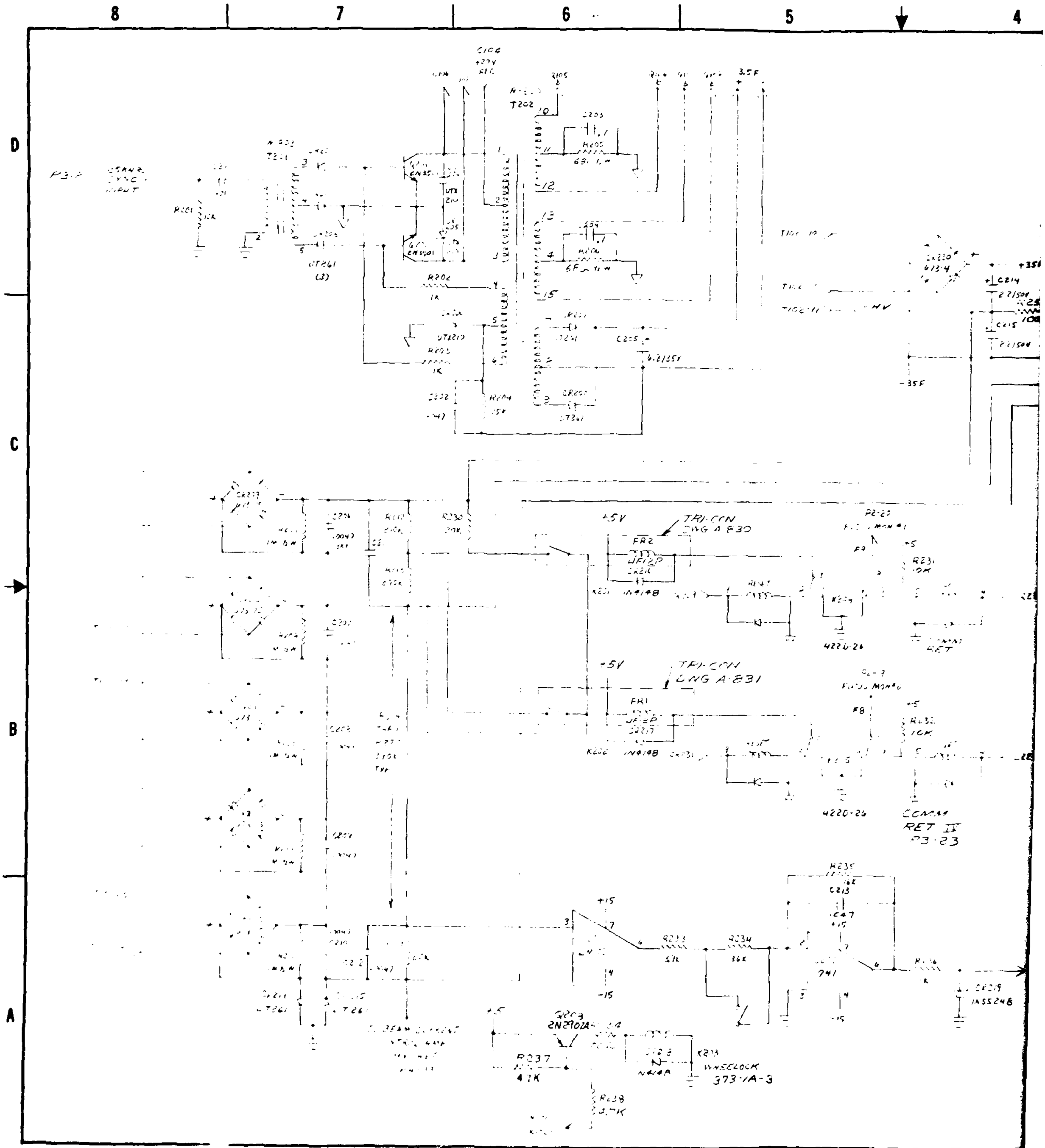
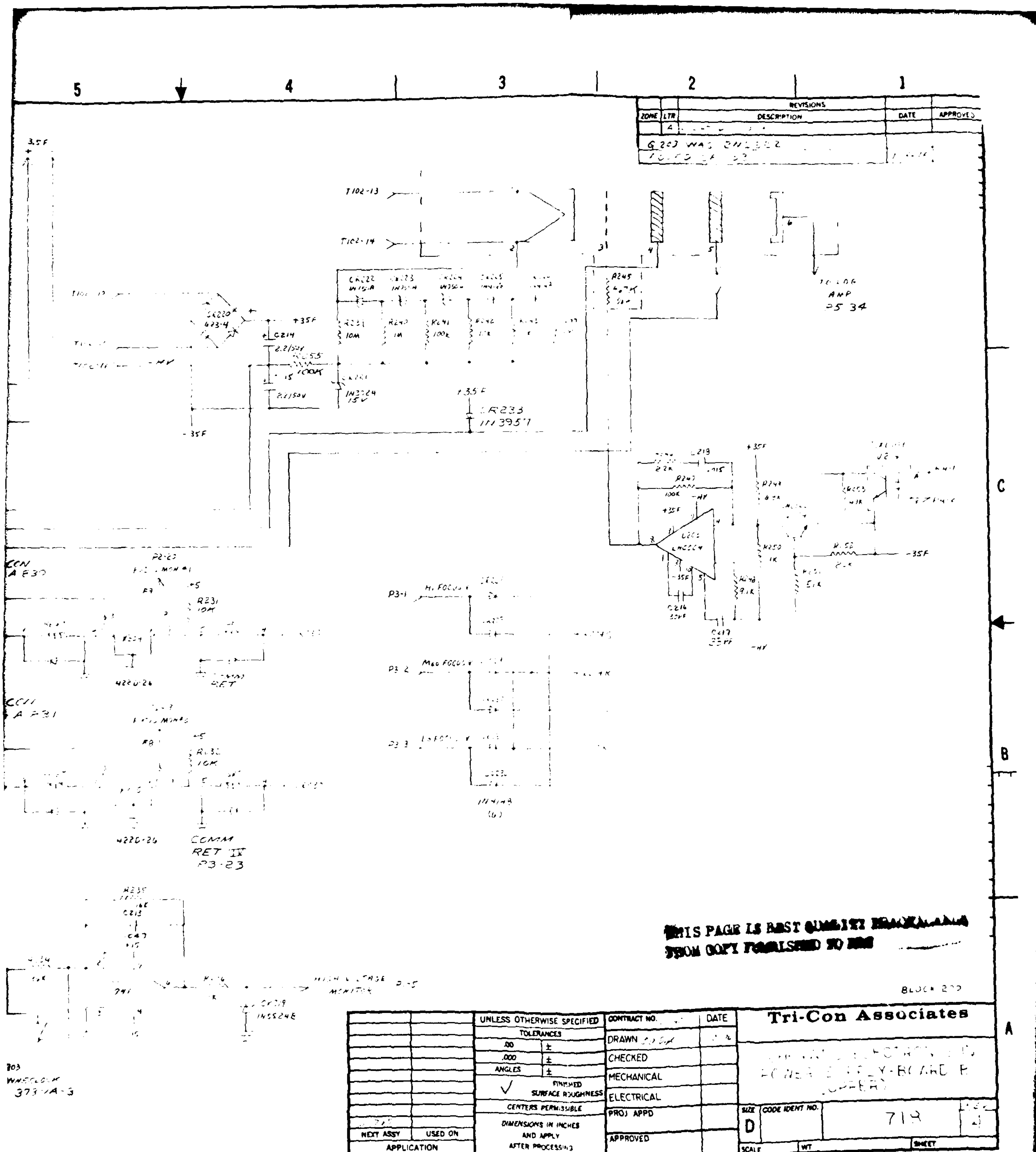
LTR
DESCRIPTION
DATE
APPROVED
+5V
P4-28
P5-28
R231
U103
78M15HM
+15V
±35V FLOATING
RECTIFIER
CR220
TO ELECTRON GUN
FILTER/CATHODE
U105
3KV
1.5KV
500V
300V
150V
50V
P3-
*PN 55C
Tri-Con Associates
UNLESS OTHERWISE SPECIFIED
TOLERANCES
.00 ±
.000 ±
ANGLES ±
FINISHED SURFACE ROUGHNESS
CENTERS PERMISSIBLE
DIMENSIONS IN INCHES AND APPLY AFTER PROCESSING
CONTRACT NO.
DATE
DRAWN
CHECKED
MECHANICAL
ELECTRICAL
PROJ APPD
APPROVED
NEXT ASSY
USED ON
APPLICATION
SIZE
D
CODE IDENT NO.
718
SCALE
WT
SHEET

Figure 1



8
7
6
5
4
D
C
B
A
T202
+5V
TRI-CON DWG A-830
FR2
IN4148
R230 20K
P2-23
R231 10K
4220-26
+5V
TRI-CON DWG A-831
FR1
IN4148
R232 10K
4220-26
COMM RET II P3-23
R235
C213
+15
-15
R233
R234 36K
741
CR219 IN5524B
Q203 2N2907A
R237 4.7K
WHEELOCK 373-1A-3
R238 3.7K


5
4
3
2
1
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DESCRIPTION
DATE
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T102-13
T102-14
TO LOG AMP
R245
R247
100K
R249
R250
1K
R252
-35F
+35F
P3-1
HI FOCUS
P3-2
MED FOCUS
P3-3
1N4148
COMM RET
P3-23
HIGH VOLTAGE MONITOR
C
B
A
BLOCK 203
UNLESS OTHERWISE SPECIFIED
TOLERANCES
ANGLES
FINISHED SURFACE ROUGHNESS
CENTERS PERMISSIBLE
DIMENSIONS IN INCHES AND APPLY AFTER PROCESSING
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USED ON
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ELECTRICAL
PROJ APPD
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Tri-Con Associates
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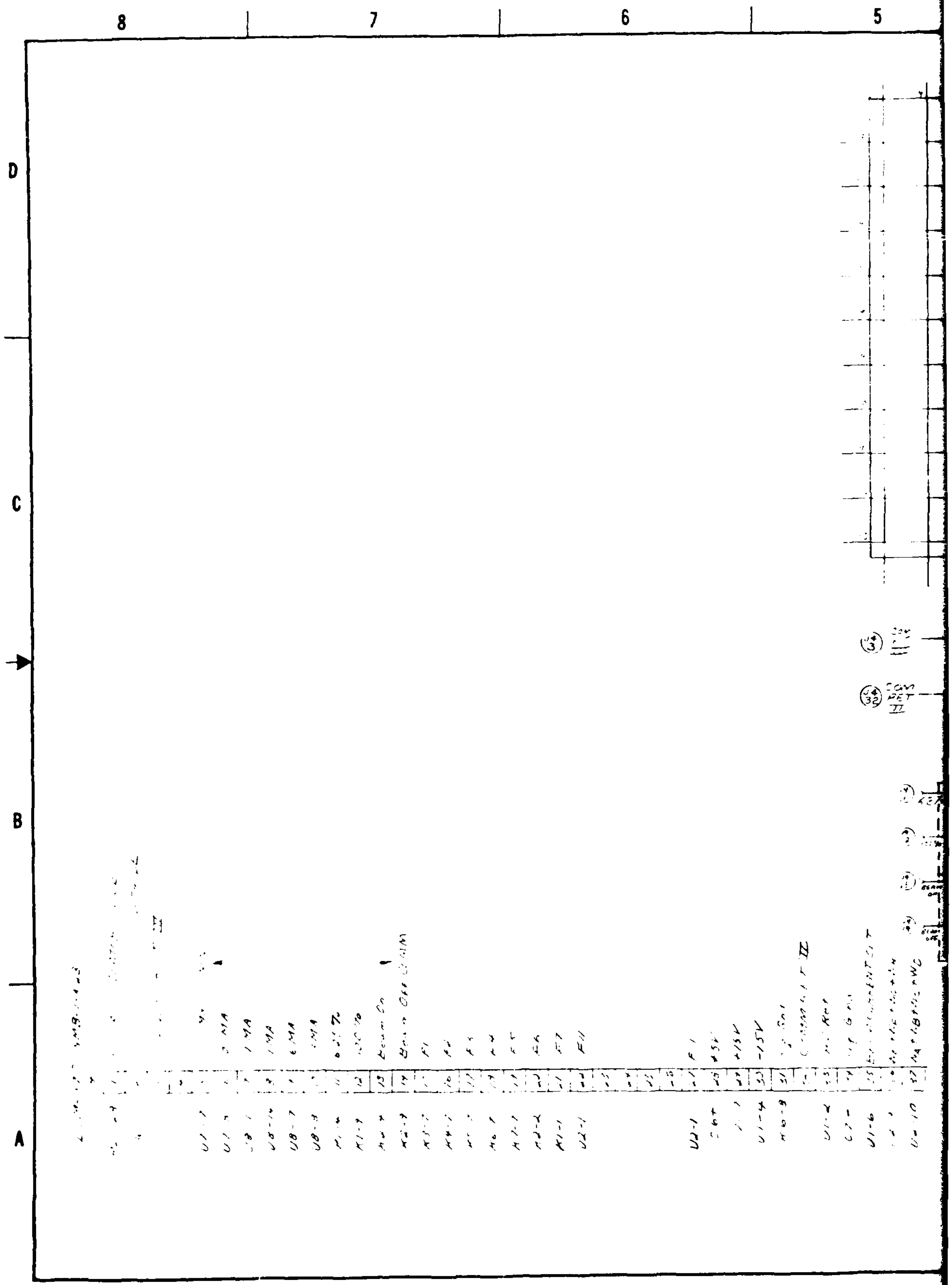
SCALE
WT
SHEET

Figure 2


8
7
6
5
D
C
B
A

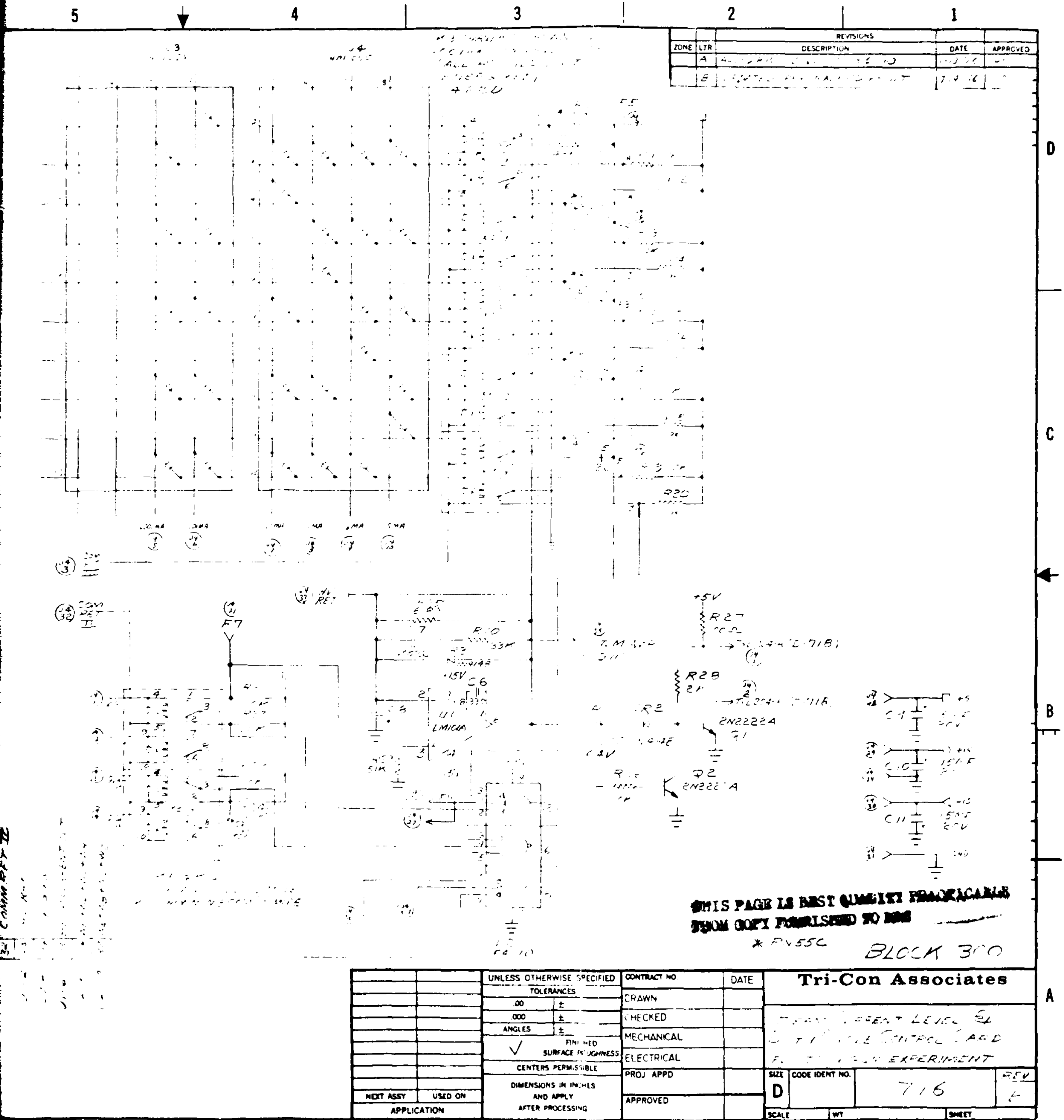


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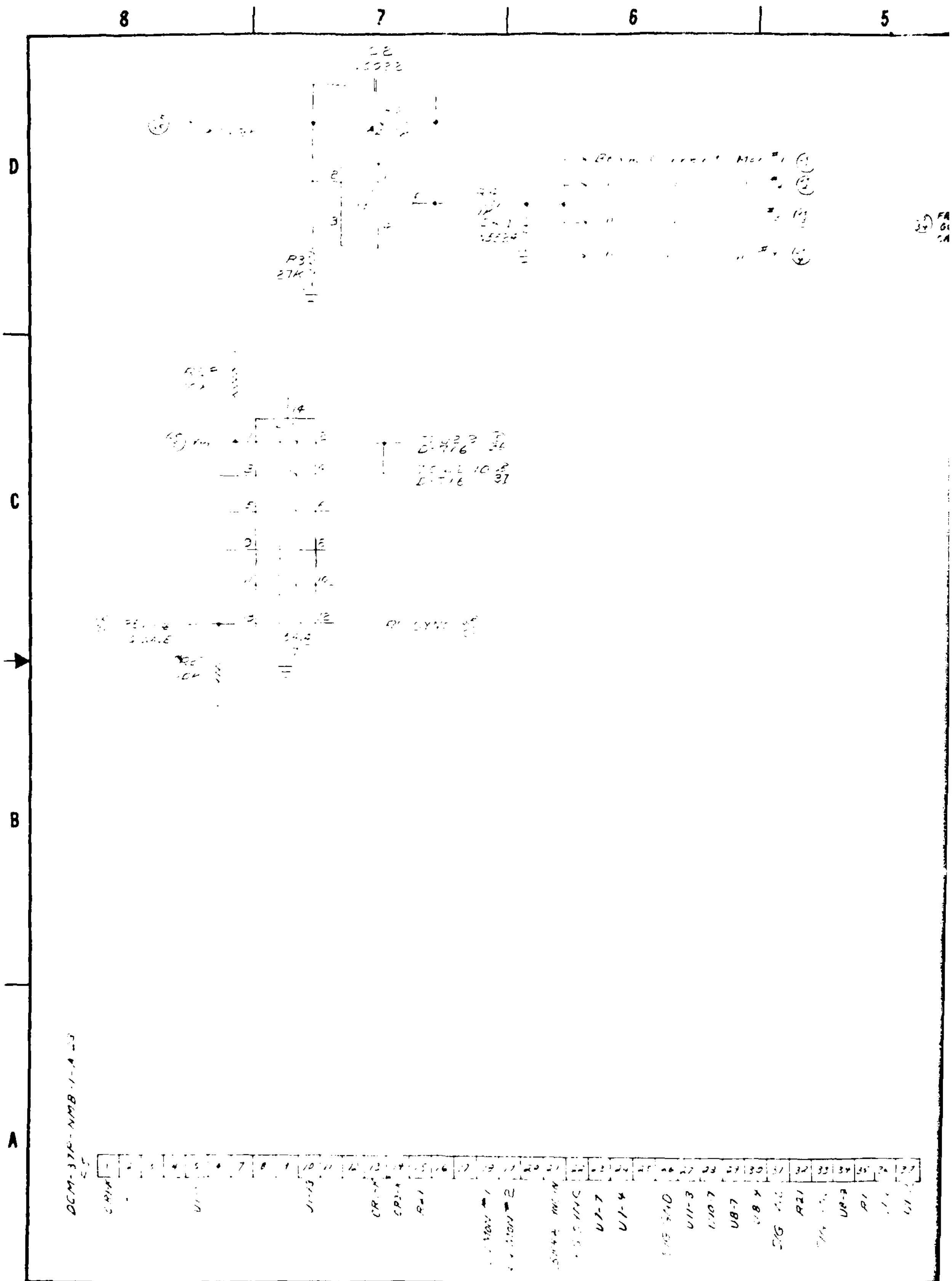
Figure 3



8
7
6
5
D
C
B
A
R3
27K
DCM-37K-NMB

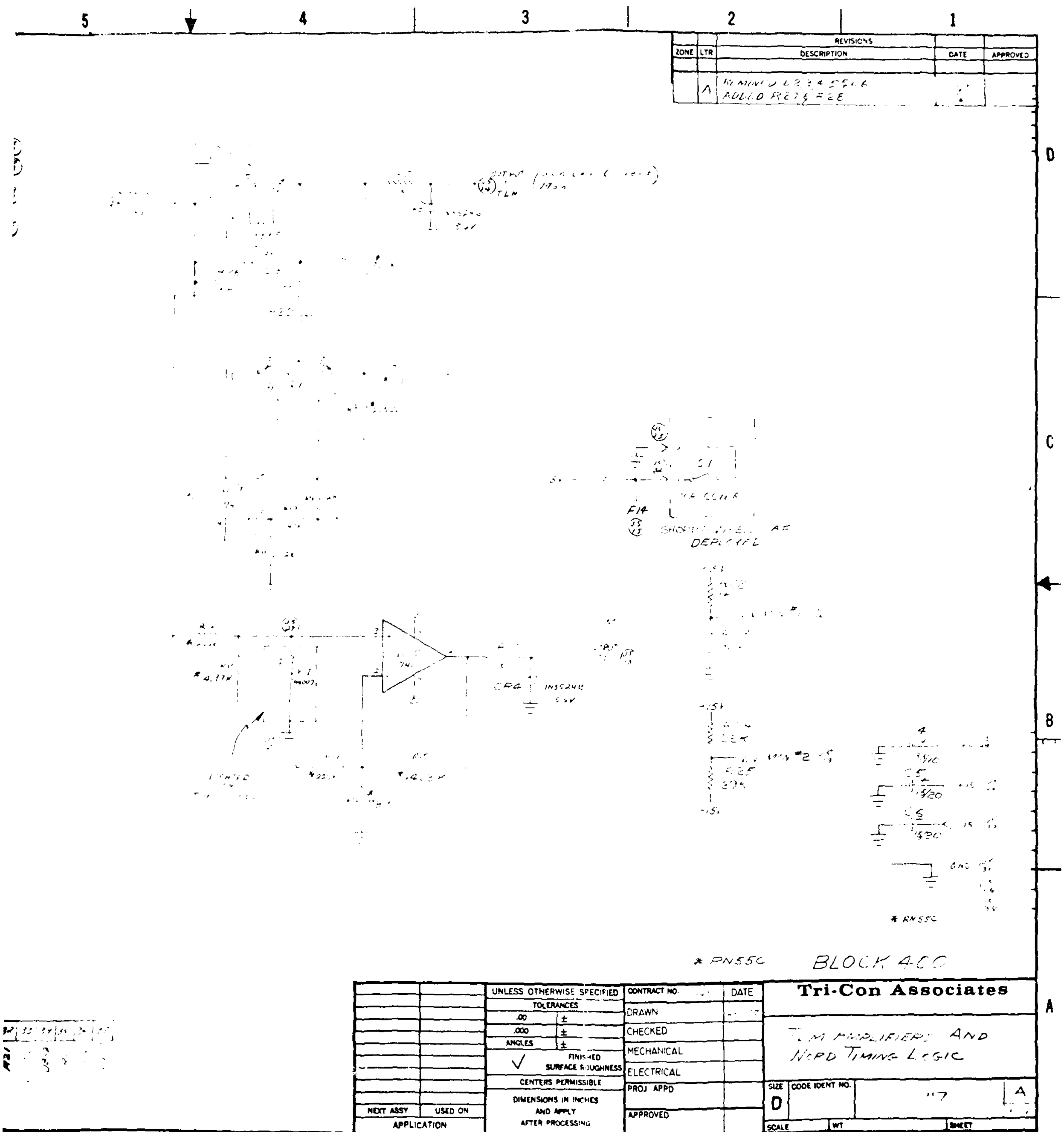

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Figure 4

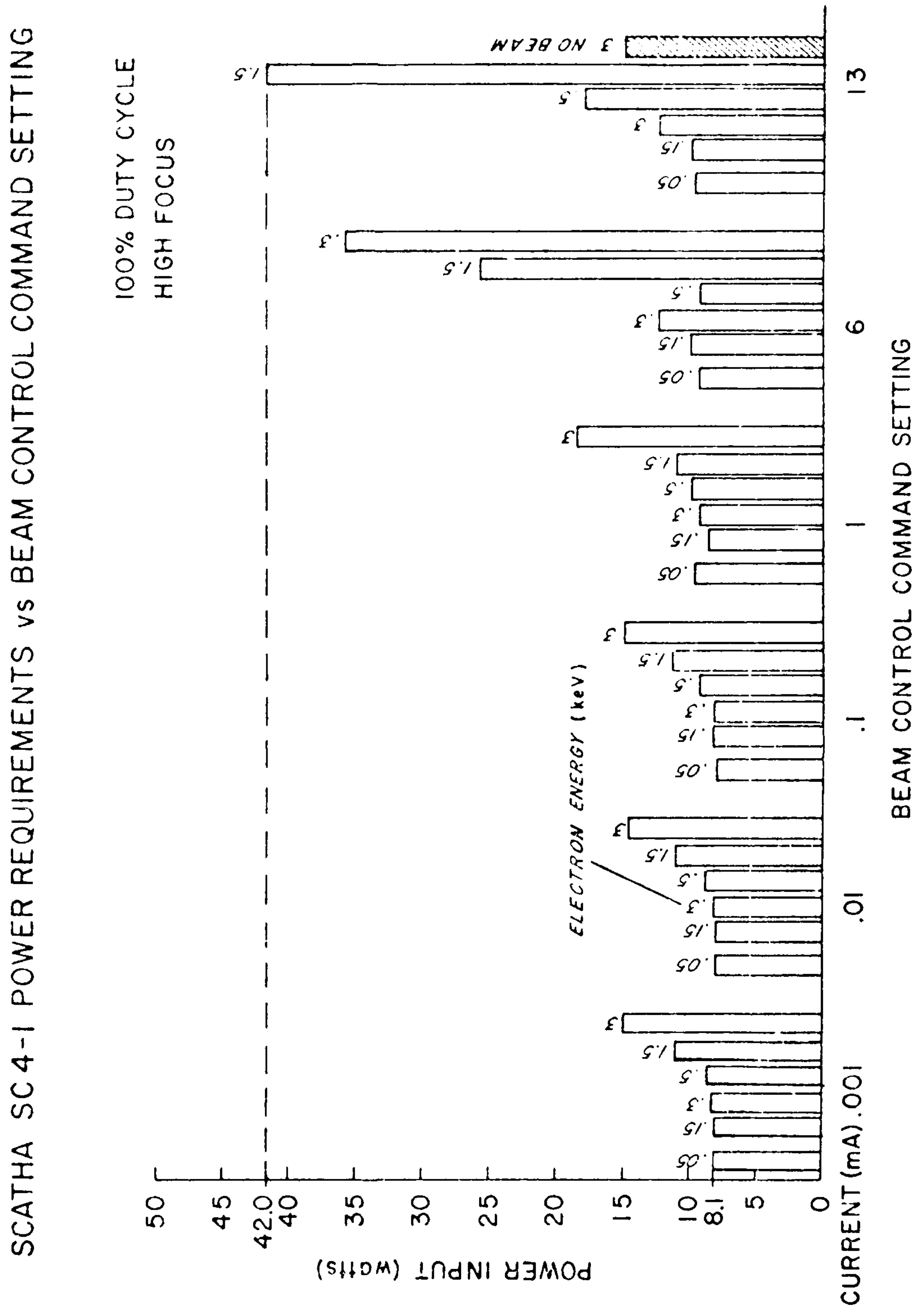
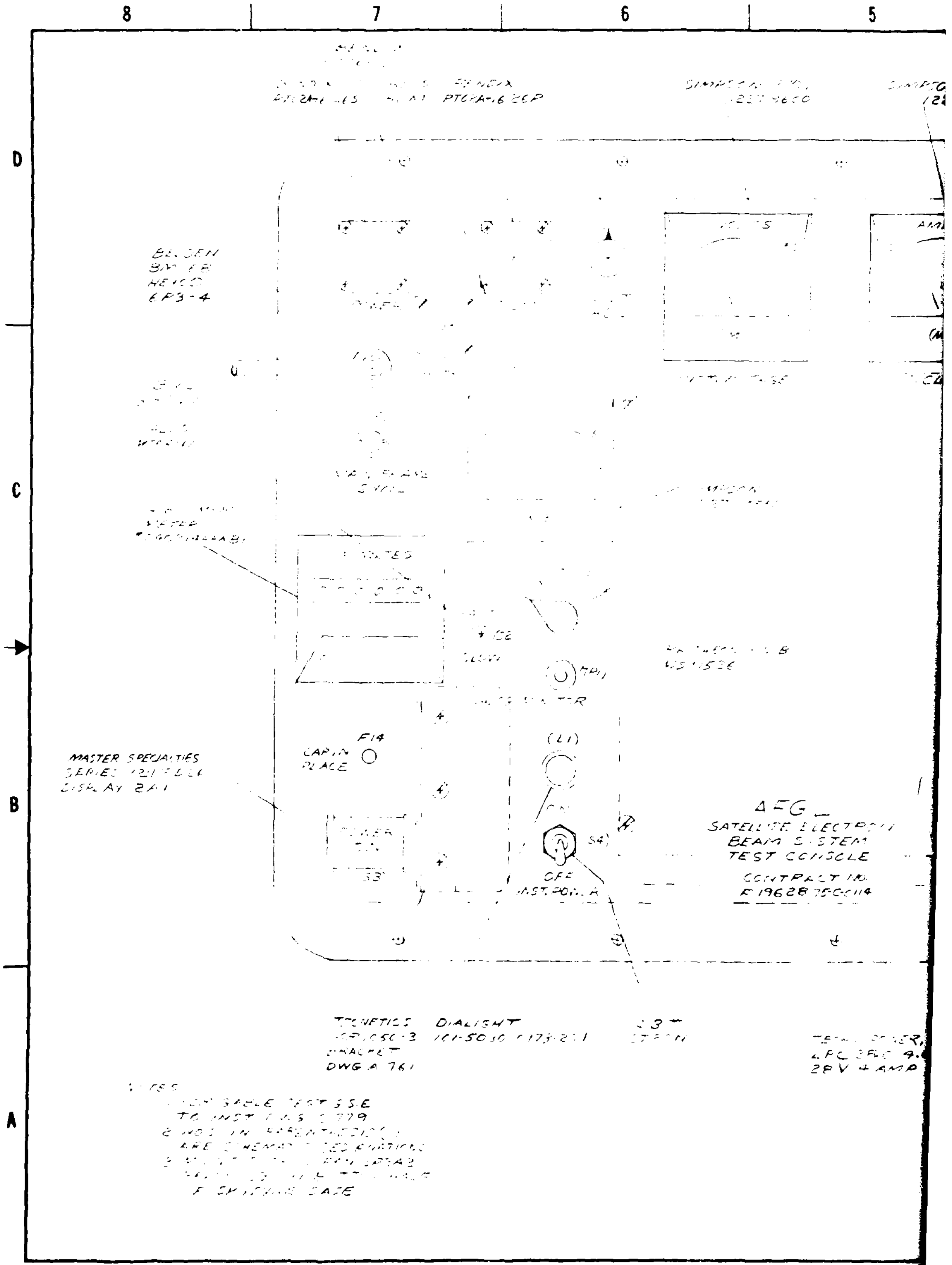
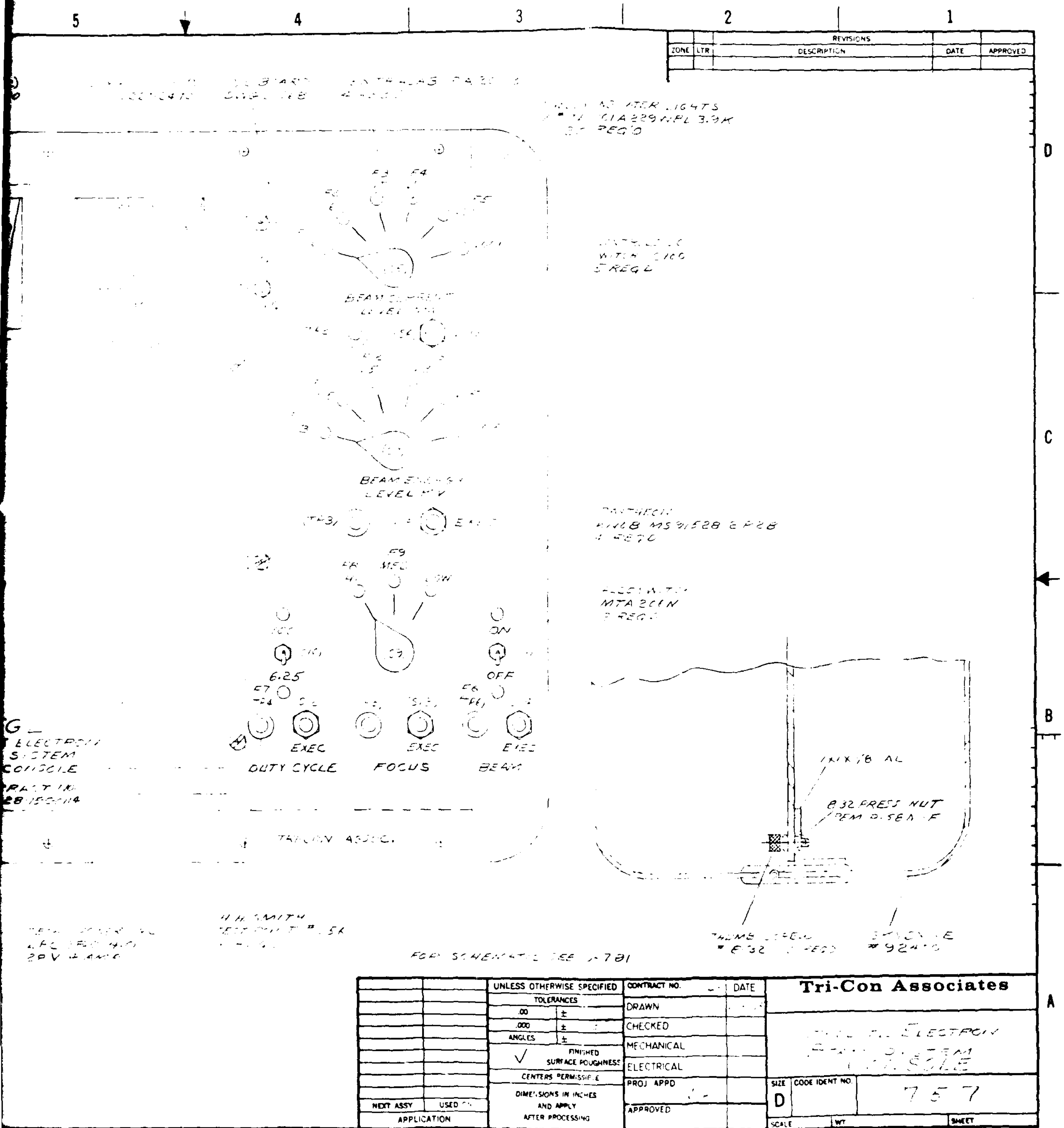

SCATHA SC 4-1 POWER REQUIREMENTS vs BEAM CONTROL COMMAND SETTING
100% DUTY CYCLE
HIGH FOCUS
POWER INPUT (watts)
50
45
42.0
40
35
30
25
20
15
10
8.1
5
0
CURRENT (mA) .001
.01
.1
1
6
13
BEAM CONTROL COMMAND SETTING
ELECTRON ENERGY (keV)
.05
.15
.3
.5
1.5
3
3 NO BEAM

Figure 5



8
7
6
5
D
C
B
A
BELDEN
MASTER SPECIALTIES
F14
CAP IN PLACE
(L1)
S4
OFF
SATELLITE ELECTRON
BEAM SYSTEM
TEST CONSOLE
DIALIGHT
DWG A 761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BEAM ENERGY LEVEL
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BEAM
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8.32 PRESS NUT
FOR SCHEMATIC SEE
UNLESS OTHERWISE SPECIFIED
TOLERANCES
ANGLES
FINISHED SURFACE ROUGHNESS
CENTERS PERMISSIBLE
DIMENSIONS IN INCHES AND APPLY AFTER PROCESSING
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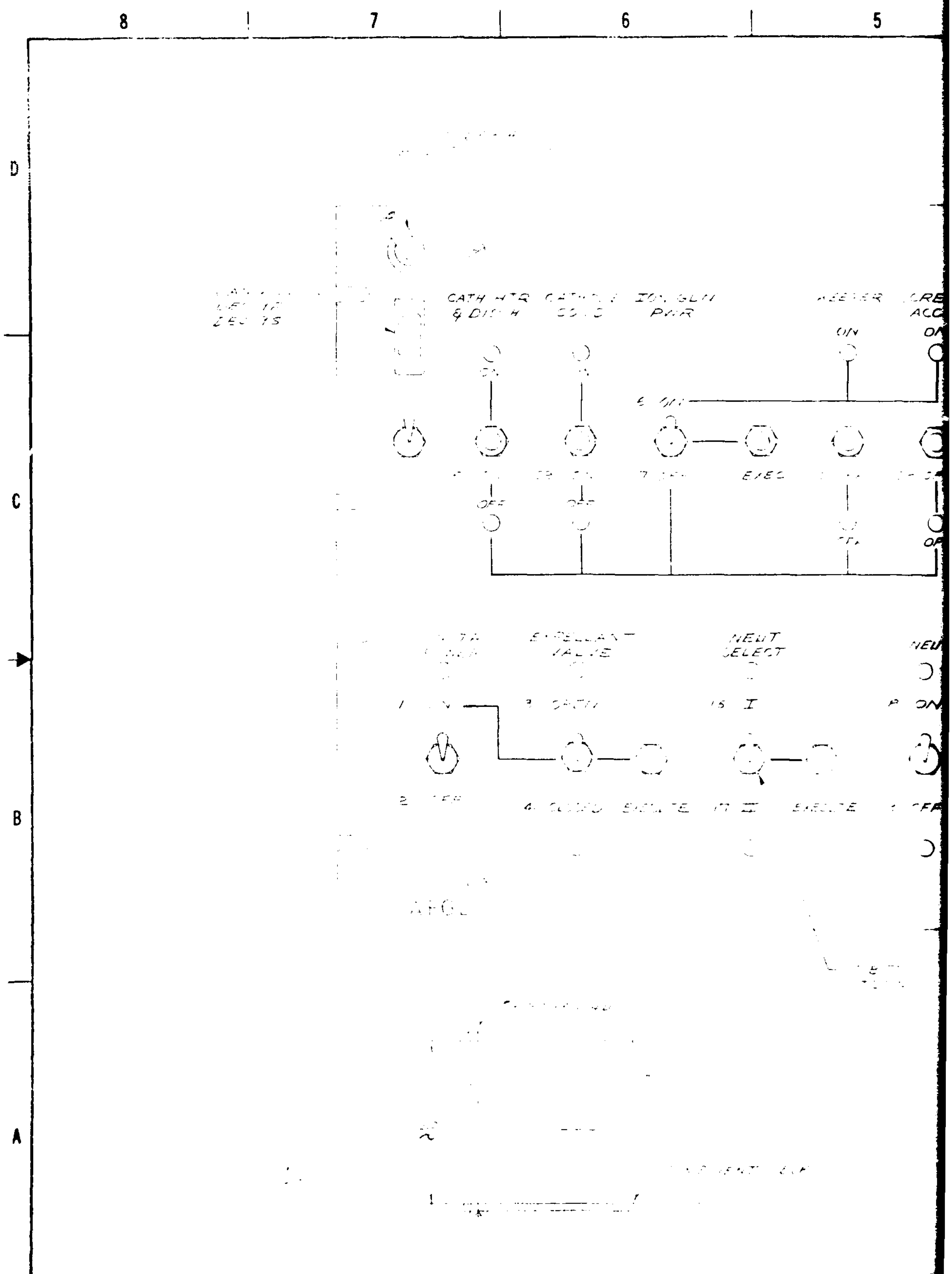
Figure 6



CATH HTR & DISCH
ION GUN PWR
ON
EXEC
OFF
NEUT SELECT
EXECUTE

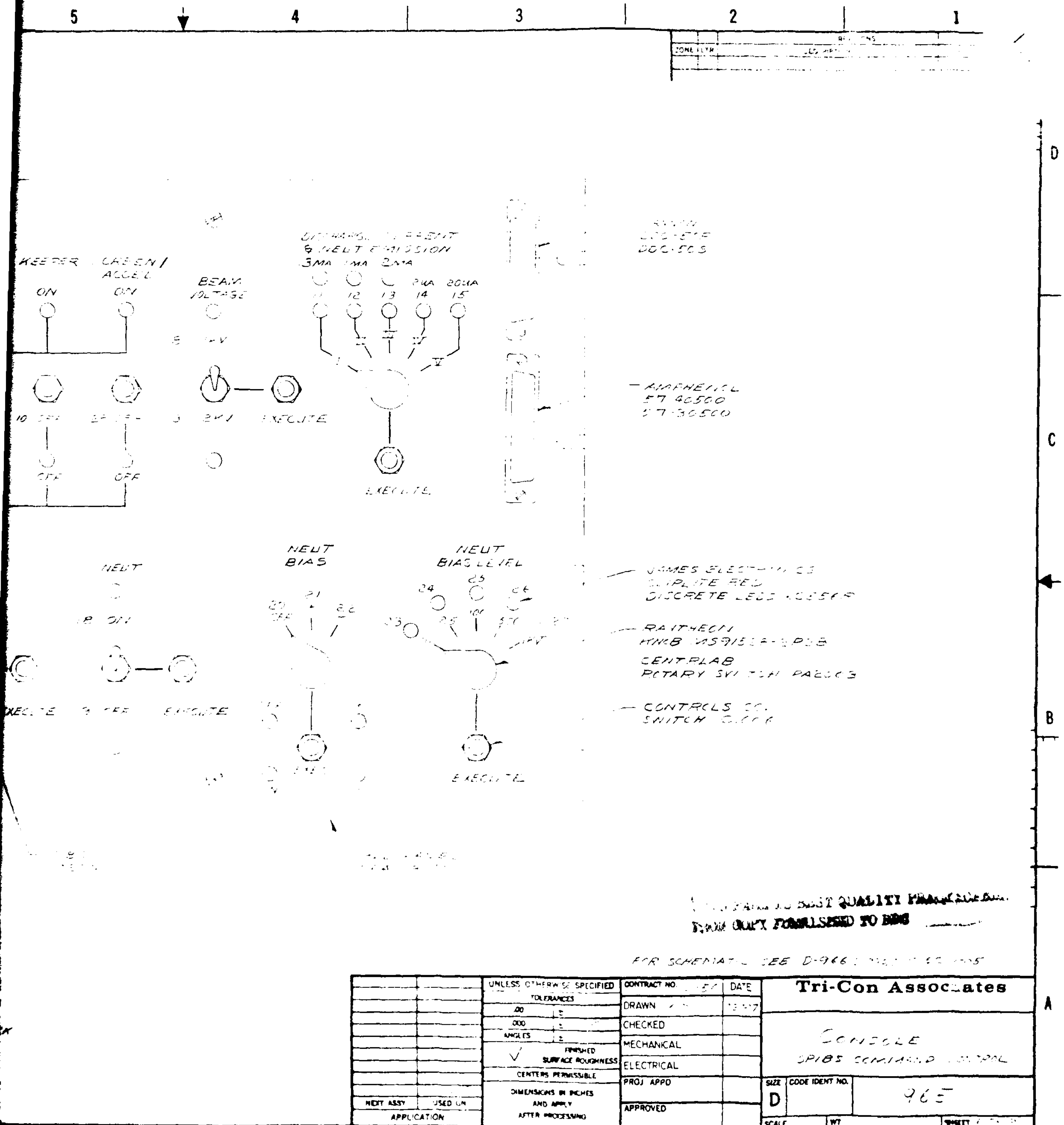

KEEPER
ON
OFF
BEAM VOLTAGE
EXECUTE
NEUT
NEUT BIAS
NEUT BIAS LEVEL
AMPHENOL
57-40500
57-30500
RAYTHEON
CENTRALAB
ROTARY SWITCH
CONTROLS CO.
SWITCH
BEST QUALITY
COPY FURNISHED TO DDC
FOR SCHEMATIC SEE
UNLESS OTHERWISE SPECIFIED
TOLERANCES
ANGLES
FINISHED SURFACE ROUGHNESS
CENTERS PERMISSIBLE
DIMENSIONS IN INCHES AND APPLY AFTER PROCESSING
NEXT ASSY
USED ON
APPLICATION
CONTRACT NO.
DATE
DRAWN
CHECKED
MECHANICAL
ELECTRICAL
PROJ APPD
APPROVED
Tri-Con Associates
CONSOLE
SIZE
D
CODE IDENT NO.
SCALE
WT
SHEET

Figure 7

DAT
FILM